

The logo for BALTIC COMPASS, featuring the word "BALTIC" in a large, bold, black sans-serif font above the word "COMPASS" in a similar font. A red compass rose icon is integrated into the letter "C" of "COMPASS".

BALTIC COMPASS

Part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument)



Baltic Sea Region
Programme 2007-2013



EXTRUSION OF SOLID PLANT BIOMASS

Technology contributing to a sustainable and profitable biogas production

Extrusion of solid plant biomass

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Published by Agro Business Park A/S, Niels Pedersens Allé 2, DK-8830 Tjele, www.agropark.dk.

Front-page Extruder at AU Foulum's biogas plant. Photo: Henning Lyngsø Foged.

Back page Round bales with wilted grass from Nørreådal, which is to be teared and extruded before it is fed to the biogas plant at AU Foulum. Photo: Henning Lyngsø Foged.

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Date December 2012

This pamphlet is part-financed by the EU's Baltic Sea Programme, and produced by Agro Business Park and AU Foulum under the auspices of Baltic Compass.

Baltic Compass is a strategic project that aims to foster solutions of benefit to both agriculture and environment in the Baltic Sea Region. The 22 partners of the project represent national authorities, NGO's, scientific institutions and innovation centers from the countries in the Baltic Sea Region. Learn more at www.balticcompass.org.



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Extrusion gives solid plant biomass good qualities for co-digestion with slurry

>> Slurry is normally the basic substrate used for biogas production. However, it is decisive for a profitable biogas production that the energy content in the organic part of the influent biomass is as high as possible. Normally, it is possible to pump liquid biomass with up to 12.5 % dry matter, which is significantly more than the 4 – 9 % dry matter that is typical for slurry. Solid plant biomass like meadow grass and deep bedding can increase the percentage of dry matter in slurry-based substrates, and pre-treating it with extrusion boosts its biogas potential and makes it easy to mix homogeneously into the liquid substrate in the digester tank.

Anaerobic digestion of slurry is a technology that involves various advantages for the aquatic environment, the climate, and the food safety. Since slurry from cattle and pigs containing only 4 – 9 % dry matter (see Table 1) accounts for the vast majority of substrate it is difficult to have a profitable biogas production; the 91 – 96 % water in the slurry means that the production of biogas is low compared to the investment costs concerning storage, stirring, and pumps.

TYPICAL QUALITY OF PIG AND CATTLE SLURRY (AVERAGE FROM AGRO-TECHNOLOGY-ATLAS.EU).

	% dry matter	Kg N / ton	Kg NH4+-N / ton	Kg P / ton
Cattle slurry	8.93	4.06	2.33	0.89
Pigs slurry	5.48	4.53	2.98	1.22

A profitable biogas production requires that the slurry is mixed with substrates containing more dry matter so that the influent biomass reaches 10 – 12 % since it is normally not possible to pump liquids with more than 12.5 % dry matter.

When choosing the substrates to be used for co-digestion three things are particularly important:

- Biogas potential
- Price
- Sustainability criteria

Waste products from e.g. food processing are suitable for co-digestion, but the amount is limited and it is difficult for new biogas plants to find this type of organic waste product to buy.

The usage of crops such as maize has increased and provides a good biogas output. The disadvantage is that these crops have a high price compared to waste products, and their prices fluctuate with the cereal prices. Furthermore, the crops are being accused of seizing soil that could otherwise have been used for cultivating food. In both Denmark and Germany it has been decided to introduce regulations in order to limit the use of maize in biogas production.

The common opinion is that biogas should be produced on residual products and bi-products. In this regard, it would be interesting to increase the dry matter content in the substrate with bedding, grass from nature areas, and straw. Available amounts of these types of biomass are increasing due to changed production systems in agriculture, and they are free besides from the handling costs. This pamphlet informs how extrusion can increase solid plant biomass' suitability and potential for biogas production.



GRASS-CLOVER SILAGE BEFORE (TO THE RIGHT) AND AFTER (TO THE LEFT) EXTRUSION. PHOTO: MICHAEL TERSBØL.

Using solid plant biomass in biogas plants have many advantages

>> The extrusion of grass from nature areas or of deep bedding increase the biogas potential of these biomasses by app. 30 % if the retention time is short, but also entails a number of other advantages: it can reduce leaching of nutrients to the aquatic environment, it can enhance the growth of organic production of especially vegetable food, it could form the basis for a more balanced feeding plan and a “super-optimisation” of biogas production. Furthermore, it is a significant circumstance that extrusion makes it possible to use solid biomasses which, besides from the handling costs, are free.

Increased biogas production

The most significant advantages of extrusion are that it is possible to feed-in and handle solid biomass in a wet digestion plant, and furthermore that the pre-treatment gives the solid plant biomass a significantly higher biogas potential.

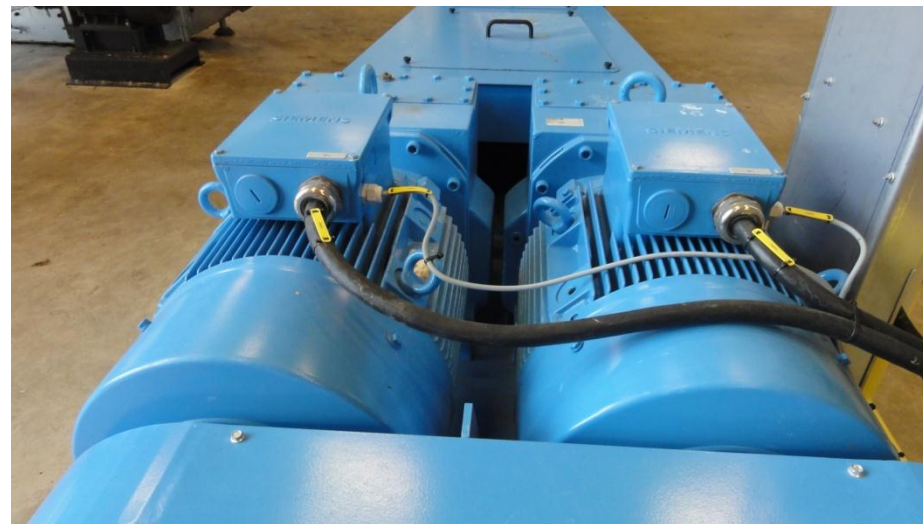


WHEN EXTRUDING DEEP BEDDING WITH A HIGH STRAW CONTENT THE BIOGAS POTENTIAL IS INCREASED BY APP. 30 % AT SHORT/NORMAL RETENTION TIMES. ADDITIONALLY, THE TYPICAL HANDLING PROBLEMS WHEN DEEP BEDDING IS USED FOR BIOGAS PRODUCTION ARE ELIMINATED.

Extrusion is a technology which is otherwise known from feed production, where it is used in order to increase the digestibility of the nutrients.

Re-circulation of the nutrients

Permanent pastures were previously used for grazing of cattle, sheep, and horses, but the tendency goes towards less grazing of dairy cattle in countries like Denmark without demands for grazing.



EXTRUSION IS A VERY POWERFUL MECHANICAL IMPACT TAKING PLACE BETWEEN TWO ROLLERS, EACH WITH A LARGE MOTOR AT THE END, WHICH SPINNS IN OPPOSITE DIRECTIONS. THE EXTRUSION OPENS CELL STRUCTURES WITH A HIGH CONTENT OF LIGNIN.

For that reason it is more and more common to see permanent pastures being left aside. There is a requirement, though, to keep such areas in Good Agricultural and Environmental Condition (GAEC), and that the vegetation is mowed once a year.

In Denmark the agricultural area includes around 10 % permanent pastures, while it makes up for around half of the agricultural area in the rest of EU as a whole. Typically, permanent pastures are meadows that border creeks, lakes, or the sea, in close connection to the aquatic environment.

Meadows in close connection to water courses emit their nutrients into the aquatic environment when the plant biomass disintegrates during the winter.

The vegetation on 1 ha permanent pasture is typically containing 150 kg N and 15 kg P per ha. These nutrients are recycled to the agricultural production, rather than being lost to the aquatic environment, if the vegetation is harvested and used for biogas production, and thereafter used for fertilisation of fields.



UNUTILISED AREAS WITH PERMANENT PASTURES ARE OFTEN SITUATED CLOSE TO LAKES OR CREEKS.

Organic biogas production

The number of organic holdings has increased dramatically in all member states since the reform of the Common Agricultural Policy in 1992. More than 15 % of the agricultural area in Austria and more than 10 % in Sweden are now organically farmed. Organic milk is considered the most successful organic product, but the consumers also buy a lot of vegetable products, e.g. vegetables and cereals.

Normally, in organic farming



the nitrogen is the most limiting production factor, since mineral fertilisers are not used, and so far, any type of organic food production has been linked to own production of manure or import of conventional manure.

By harvesting the vegetation at otherwise unutilised permanent pastures, using it for biogas production, and using the digestate as fertiliser on the fields, it is possible to

- Increase the organic vegetable food production without livestock farming; and
- Become self-sufficient regarding both energy and plant nutrients, in line with the organic farming principles.

In other words, the extrusion of solid plant biomass could become a technology that significantly can contribute to a further expansion of the organic farming production.



THE SUPPLY OF PLANT NUTRIENTS FOR ORGANIC VEGETABLE PRODUCTION COULD BE BASED ON DIGESTATE FROM HARVESTED VEGETATION AT OTHERWISE UNUTILISED AREAS.

Balanced feeding of the biogas plant

Optimal biogas production is based on a feeding plan where the nutrients are as digestible as possible and also balanced in order to optimise the microbiologically based methane production.

In general, a feeding plan based on different types of biomass results in a more stable biogas production because the nutrients complement one another; if one type of biomass has a specific shortage of a certain nutrient, there is probably a surplus in another.

One of the significant conditions for optimal biogas production is the proportion between carbon and nitrogen, the C:N-ratio. An optimal C:N ratio is between 20 and 30, but in pig slurry it is often lower, and in cattle slurry it is higher. In meadow grass and bedding the C:N ratio is often low, and the usage together with pig slurry should therefore be limited to an extent that does not increase the C:N ratio to more than 30.

“Super-optimisation” of the biogas production

As previously mentioned, it is not possible to pump liquids with a dry matter percentage above app. 12.5 %, and the biogas is produced on the basis of the organic fibres. Therefore, the dry matter content of the digestate is often around half of the dry matter in the biomass fed into the digester tank, meaning around 4-6 %.

Since the extruded biomass is fed-in separately it is not necessary to pump it into the digester tank, which can therefore be operated with a higher percentage of dry matter than usual. This in turn causes a higher biogas production per m3 digester tank volume per day.

Extrusion enables the usage of biomass with no alternative value

The biomasses, which can be extruded with advantage, are otherwise unutilised green crops from meadows and other permanent pastures, as well as deep bedding.

The usage of these types of biomass means, besides the already mentioned advantages, that it is free to use them besides their handling costs, since they do not have any alternative value. Some value could be ascribed to deep bedding as fertiliser, but this value is only increased via extrusion and biogasification.

Thus, extrusion is a technology that makes up an attractive alternative to using e.g. maize silage to boost the slurry-based biogas production.



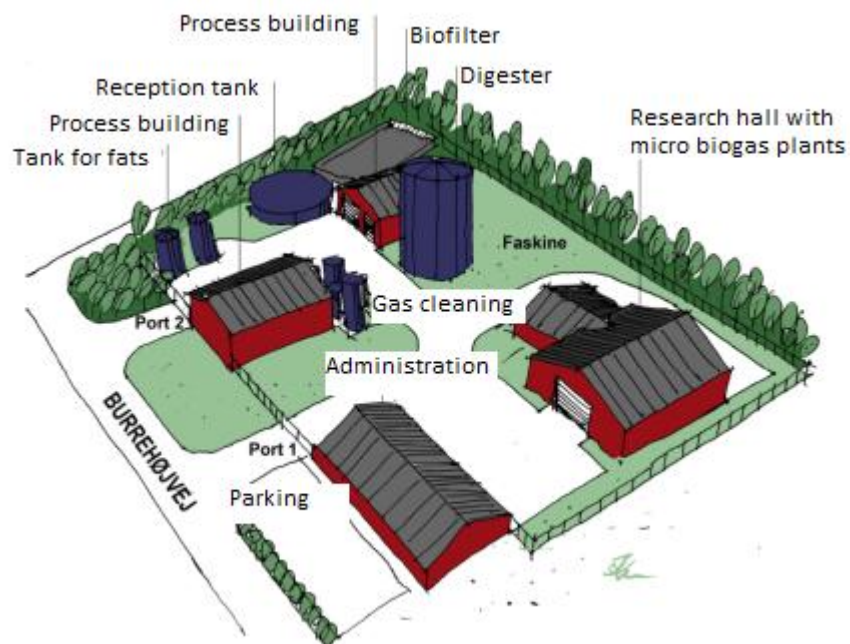
AT AU FOULUM'S BIOGAS PLANT ROUND BALES OF WILTED MEADOW GRASS IS LOADED INTO THE BIO-MIXER, WHICH AFTERWARDS FEEDS IT TO THE EXTRUDER, FROM WHERE IT IS FED INTO THE DIGESTER TANK. BESIDES FROM THE LOADING, THE PROCESS IS REGULATED AUTOMATICALLY.

The pilot project at AU Foulum's biogas plant

>> The biogas plant at AU Foulum, an agricultural research centre under Aarhus University, was inaugurated in 2006. It includes a commercial size plant that treats manure from all livestock at the research centre, a hall with 2 x 10 m³ and 2 x 30 m³ digestion tanks for lab experiments in a large scale, plus a number of micro-plants with 125 litres digesters. Because of its configuration and the connected teams of biogas and biomass researchers, the biogas plant forms a unique basis for biogas research on a high level. The installed extruder makes up one of the elements in a development plant that will turn the biogas plant into a bio refinery.

The biogas plant at AU Foulum

The biogas plant at AU Foulum was established in 2006 for the purpose of carrying out research on biogas production on a high level.



SCHEMATIC OVERVIEW OF THE AU FOULUM BIOGAS PLANT, PRIOR TO THE INSTALLATION OF THE EXTRUDER.

In the figure the Digester is a commercial size digestion tank with a capacity of 1,200 m³, the Process Building to the left contains four complete biogas plants with 2 x 10 m³ and 2 x 30 m³ digester tanks. The Research hall contains a number of micro-plants with 125 litre digesters. The biogas plant

also includes a well-equipped lab in the administration building. Thus, the unique plant is ideal for executing a wide range of digestion experiments.

Further development to bio refinery

AU Foulum wants to develop the plant further in order to make it a bio refinery, making it able to handle more types of biomass, give it more different types of treatments, and to refine and convert them into more products than just biogas and digestate.

One of the most urgent wishes is to be able to extrude biomass like deep bedding or meadow grass and other vegetation from permanent pastures. The wish is based upon the following objectives:

- To be able to decouple the continuously increasing organic farming production of vegetable foods from organic livestock farming, and to be able to gain access to nutrients for fertilising by other means;
- To work for sustainability in the bioenergy production;
- To support the political goals for a bio-based society.

The extruder

The investment in the extruder includes, besides from the extruder itself, a bio-mixer that tears up the round bales and feeds the extruder, plus a conveyer belt and conveyer screws, which feed the extruded material into the digester tank. The extruder is placed in an open and un-insulated steel hall, while the control system and power supply is in a separate room.



THE BIO-MIXER TO THE LEFT AUTOMATICALLY FEEDS THE TORN APART BIOMASS INTO THE EXTRUDER FROM WHERE IT IS LED TO THE DIGESTER TANK.



A ROOM BEHIND THE EXTRUDER CONTAINS POWER SUPPLY AND CONTROL SYSTEM.

The total investment costs are € 875,000, from which the extruder itself has cost € 185,000.



Monitoring, registrations and analyses

>> The extruder has been used for wilted meadow grass, deep bedding, and maize silage. As expected, the extrusion of wilted meadow grass and deep bedding has increased the biogas output of these biomass types with app. 30 %. On the contrary, the maize silage has not given any noticeable increase in biogas potential after extrusion. The energy used for the bio-mixer and extruder has only made up around 10-25 % of the energy of the increased biogas production.

Commissioning

The plant was started up at the beginning of August 2012 and has since then treated app. 15 tons of biomass a day with varying dry matter content.

Two capacity tests were done prior to the delivery of the plant in order to demonstrate the capacity of the bio-mixer and the total capacity of the plant.

The test of the bio-mixer showed that a round bale can be torn up in less than 10 minutes, and it is possible to contain app. 7 bales in the mixer. Subsequent, under normal working circumstances, biomass with a lower content of dry matter will be added onto the meadow grass, e.g. deep bedding, grass or maize silage, in order to reach a mixture with a dry matter percentage of 45 -55 %.

The test of the complete plant was executed on a mix of meadow grass and grass silage with a total dry matter percentage of app. 55 %. The total capacity of the plant was measured to 1.4 tons per hour, which meets the expectations regarding a total plant capacity of 30 tons a day at a dry matter percentage of 55 %.

The expectations to the extruder has been met so far, since it in this way has been possible to add extra dry matter to the biogas plant, increasing the dry matter percentage in the digester tank from around 5 % to around 8 – 9 %. At the same time, the gas production has increased, meaning that the plant today produces around 5,000 m³ of biogas/day in the 1,200 m³ digester tank.

Extruded biomass

During the operation period from August to November 2012, the following biomasses have been treated in the extruder plant:

- Meadow grass haylage (dry matter 70 – 85%)

- Deep bedding (dry matter 25 – 45%)
- Clover grass haylage (dry matter 80 – 85%)
- Straw (dry matter 75 – 85%)
- Grass and maize silage (dry matter 25- 35%)

The biomasses are mixed in the bio-mixer in order to reach an average of around 50 % dry matter in the biomass that is fed into the extruder.

Increased biogas output

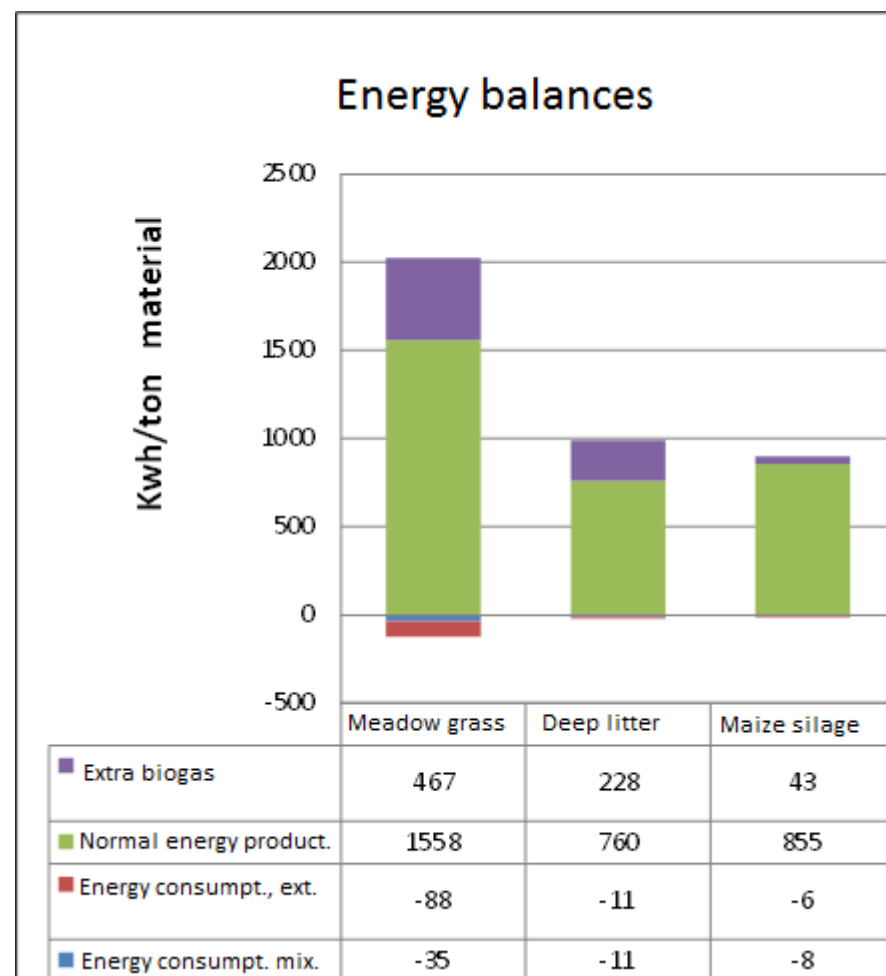
Biogas production tests with grass, deep bedding, and wheat straw has been carried out, and the output is increased significantly when they undergo extruding as pre-treatment. The extra output regarding the three biomasses is 15-27 % when the fermentation time is 20-30 days, and at long-range fermentation the increase is 1-10 %. If the retention time is too long the effect is limited. On the other hand, the extruder makes it possible to increase the strain on the reactor at shorter retention times without any problems with floating layers.

Power consumption

A number of tests of the biogas potential have been out regarding the biogas potentials of straw, grass, and solid manure, here under also with and without extrusion as pre-treatment.

The capacity and the power consumption for extrusion have been measured and a number of adjustments have been made in order to optimise the operation. The figure below shows the energy production and consumption for three types of biomass. A considerable increased energy output is gained by extruding deep bedding and meadow grass. Only 10-25 % of the extra

energy is used for the pre-treatment. The power consumption for the extrusion is much depended on the dry matter content of the biomass.



ENERGY BALANCES REGARDING EXTRUSION.

Work consumption

The work hours spend on running the extruder is mainly for:

- Transportation from storage to bio-mixer.

- Manual removal of nets on bales.
- Waiting time when dosing the bales, a maximum of 1 bale can be dosed every 10th minute. A total of app. 6 – 7 bales, which is around 2.5 - 3 tons.
- Mixing with other biomasses with a low percentage of dry matter, e.g. grass silage.

Thus, the time consumption per ton meadow grass is around 20 minutes and the total time consumption per mix consisting of app. 50 % meadow grass and app. 50 % grass silage is around 15 minutes per ton with around 50 % dry matter in the final mixture.

Other costs and expenses

Four months of operating time is a relatively short period of time to base conclusions on maintenance costs on. However, it is expected that maintenance costs will be more than € 1.3 per ton.



MIX OF GRASS SILAGE AND DEEP BEDDING AFTER EXTRUSION. PHOTO: MICHAEL TERSBØL.

Further information

>> Literature, websites, etc., where you can find further information on extrusion of solid plant biomass.

- AgroTechnologyATLAS - <http://agro-technology-atlas.eu/>.
- Baltic Compass – <http://www.balticcompass.org>.
- Sector Study concerning prioritised innovative agro-environmental technologies for sustainable food production in the Baltic Sea Region - http://agro-technology-atlas.eu/docs/repo20905_Baltic_Compass_Sector_Study.pdf.
- “Win-win technologies for nutrient management” – a mobile and partly virtual exhibition with video clips and PowerPoints - http://agro-technology-atlas.eu/win_win_technologies_for_nutrient_management.aspx.

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